AFWAL-TR-81-3127
Volume I

TANKER AVIONICS/AIRCREW COMPLEMENT EVALUATION (TAACE)

PHASE I - SIMULATION EVALUATION

Volume I: Results

THE BUNKER RAMO CORPORATION
ELECTRONIC SYSTEMS DIVISION
WESTLAKE VILLAGE, CALIFORNIA

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FLIGHT DYNAMICS LABORATORY
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NOTICE

This technical report has been reviewed and is approved for publication.

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ERRATA

PLEASE MAKE THE FOLLOWING CORRECTION:

Located in AFWAL-TR-81-3127 - TANKER AVIONICS/AIRCREW COMPLEMENT EVALUATION (TAACE) PHASE I - SIMULATION EVALUATION Volume I: Results

On Page 7, line 8; please change the word "not" to "now". (1st paragraph)

Richard W. Moss
AFWAL/FIGR/56670

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Nav Management System	Map Display	Aerial Refueling
Horizontal Situation Display	Crew Complement	Boom Operator's Station
Multi-Purpose Display	Navigator	Control/Display Criteria

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This report documents a cockpit simulation study conducted to validate the pilot useability of a 3-man (pilot, copilot, boom operator), KC-135 crew system concept. Earlier analysis and mockup evaluation studies had established preliminary design criteria and control display arrangements. The effort reported herein draws upon this earlier work, and through full mission simulation, validates display formats, cockpit hardware arrangements and crew procedures. This report consists of two volumes: Volume I: RESULTS, and Volume II: CREW SYSTEM DESIGN. In addition a "KC-135 Crew System Criteria" document (AFWAL-TR- cont.

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20. Abstract cont'd.-

(MIL-STD-301D?) was wrriten deriving from mission statements and control display research, design criteria for operating the tanker with a reduced crew.

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FOREWORD

This report documents the second phase of a two-phase effort called the Tanker Avionics/Aircrew Complement Evaluation (TAACE) Program. The results obtained from a full mission simulation of an updated avionics configuration for the KC-135 tanker are reported herein. These results concern the development of the crew station avionics criteria to be met for a 3-man crew complement (pilot, copilot, boom operator) completing all KC-135 mission requirements without compromise to either mission performance or aircraft operational safety.

The program was conducted in support of the Aeronautical Systems Division, KC-135 Avionics Modernization Program (ASD/AFN) managed by Mr. Tom Biggs, by the Air Force Wright Aeronautical Laboratory's Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio. The Program Manager was Mr. Richard Moss, (AFWAL/FIGR). Lts Donald Seyler and Dan Basehore, both of the Crew Systems Development Branch (AFWAL/FIGR), were also involved with the Program.

The report was prepared in part by the Bunker Ramo Corporation, Electronic Systems Division, and Human Factors Group located at Dayton, Ohio, under USAF Contract No. F33615-78C-3614, Project No. 23915200. Mr. Robert A. Bondurant, III (AFWAL/FIGR) is the contract monitor.

The authors wish to acknowledge the assistance of Mr. George Sexton, the Lockheed Corporation, Marietta, Georgia, (formerly with Bunker Ramo Corp), for his critical contributions in virtually every aspect of this program. Recognition is also given to the following members of the Control Synthesis Branch (FIGD): Ms. K. Adams for simulation software/hardware design, integration and program management; Lt J. Tizard for critical software/hardware design and interface; Mr. T. Christensen and Lt D. Hawthorne for essential software/hardware design interface; and Mr. D. Lair for his consultation and expertise in software/hardware design and

interface problem solving. Further recognition is extended to the on-site Lear Siegler (LSI) group, headed by Mr. R. Hitchcock with Mr. A. LeDonne managing the engineering simulation hardware fabrication/integration. Radar landmass engineering buildup and integration was headed by Mr. J. Vesco also of LSI. Recognition is also given to the Electronic Associates Inc. (EAI) on-site support group headed by Mr. D. Cafferty, for their computer systems support. Mr. John Kozina (Bunker Ramo) and Mr. Fritz Baker (Lear Siegler) are recognized for engineering assistance in experimental equipment integration; and Cindy Gier and Sandy Dickey (Bunker Ramo) for untiring administrative support.

This research effort was performed between June 1979 and June 1980.

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LIST OF ABBREVIATIONS

A/A	Air to Air
AC	Alternating Current
ADF	Automatic Direction Finding
ADI	Attitude Director Indicator
AFB	Air Force Base
AFTO	Air Force Tech Order
AFWAL	Air Force Wright Aeronautical Laboratory
AHRS	Attitude Heading Reference System
AIC 10	Interphone Unit
AIC 18	Interphone Unit
AOA	Angle of Attack
A/P	Autopilot
APP	Approach
APN 59	Search Radar
APN 69	Beacon Radar
APU	Auxiliary Power Unit
AR	Air Refueling
[illegible]	Airborne Radar Approach
ARCP	Air Refueling Control Point
ARCT	Air Refueling Control Time
ARIP	Air Refueling Initial Point
ATC	Air Traffic Control
BAR	Begin Air Refueling
BDHI	Bearing Distance Heading Indicator
BO	Boom Operator
BRG	Bearing
BRT	Bright
CADC	Central Air Data Computer
CAS	Calibrated Airspeed
CCW	Counter Clockwise
C/D	Control/Display
CDI	Course Deviation Indicator
CDU	Control/Display Unit
CLR	Clear
CG	Center of Gravity
CLTR	Clutter
CMPTR	Computer
COMM	Communication
CON	Contrast
CONUS	Continental United States
CP	Copilot
CRS	Course
CRT	Cathode Ray Tube
CTR	Contour
CURS	Cursor
C/W	Caution/Warning
DC	Direct Current
DF	Direction Finder

LIST OF ABBREVIATIONS

(Cont'd)

DFT	Drift
DIR	Direct
DIST	Distance
DME	Distance Measuring Equipment
DOT	perations/Training Office
DR	Dead Reckoning
E	East
EAR	End of Aerial Refueling
EGT	Exhaust Gas Temperature
EMP	Electromagnetic Pulse
EPR	Engine Pressure Ratio
EWO	Emergency War Order
FAF	Final Approach Fix
FD 109	Flight Director
FDL	Flight Dynamics Laboratory
F/F	Fuel Flow
FIGD	Control Synthesis Branch
FIGR	Crew Systems Development Branch
FL	Flight Level
FLT	Flight
FM	Frequency Modulation
FZ	Freeze
GA	Go Around
GCI	Ground Controlled Intercept
GMT	Greenwich Mean Time
GS	Groundspeed
HF	High Frequency
HSD	Horizontal Situation Display
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
IAS	Indicated Airspeed
IC	Intercomm
ID	Identification
IFF	Identification, Friend or Foe
IFF/SIF	Identification, Friend or Foe/Selective Identification Feature
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INB	Inbound
INS	Inertial Navigation System
IP	Instructor Pilot/Initial Point
JN	Jet Navigation
LOC	Localizer
MACH	Percent of Speed of Sound
MLD	Mildenhall
MGT	Management
MHz	MegaHertz

LIST OF ABBREVIATIONS

(Cont'd)

MPD	Multipurpose Display
MRT	Mulitary Rated Thrust
N	North
NATO	North Atlantic Treaty Organization
NAV	Navigation/Navigator
NM	Nautical Miles
OAT	Outside Air Temperature
OP	Operator
P	Pilot
PMD	Program Management Directive
PPSN	Present Position
RADAR	Radio Detecting and Ranging
RAF	Royal Air Force
RDAFB	Royal Danish Air Force Base
RDR	Radar
REC	Receiver
RGA	Rotate and Go Around
RMI	Radio Magnetic Indicator
RNAFB	Royal Norwegian Air Force Base
RNG	Range
ROC	Required Operational Capability
RPM	Revolutions Per Minute
RPT	Repeat
R/T	Receiver/Transmitter
RZ	Rendezvous
RZIP	Rendezvous Initial Point
S	South
SAC	Strategic Air Command
SELCAL	Selective Call
SKE	Station Keeping Equipment
SSB	Single Side Band
SXV	Saxa Vord
TAACE	Tanker Avionics/Aircrew Complement Evaluation
TAC	TACAN
TACAN	Tactical Air Navigation
TAS	True Airspeed
TK	Track
TOLD	Take-Off and Landing Data
TRT	Take-Off Rated Thrust
U-1	UHF#1
U-2	UHF#2
UHF	Ultra High Frequency
UK	United Kingdom
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
V NAV	VHF Navigation

LIST OF ABBREVIATIONS

(Concluded)

VOR	VHF Omnidirectional Range
VVI	Vertical Velocity Indicator
W	West
WPT	Waypoint
WX	Weather

SUMMARY

The USAF is considering an avionics modernization program for the KC-135 fleet and is also considering the feasibility of operating the KC-135 without a navigator (SAC ROC 5-74 w/amendments). In response to a request from the Aeronautical Systems Division, the Flight Dynamics Laboratory has recently completed a full mission simulation in which operationally qualified SAC tanker crews validated a KC-135 cockpit configuration designed to permit operating the tanker, without a navigator, throughout its broad spectrum of mission tasks. Critical to the success of this effort is the fact that prior to full mission simulation, three candidate crew system concepts were developed and evaluated by nine SAC aircrews during preliminary mockup studies in which the crew useability/acceptability of the three original designs was assessed. While all three designs remained responsive to the mission and manning requirements, they differed considerably in control and display sophistication and, therefore, total system cost. This development of alternative designs permitted early exploration of trade-offs between cockpit/crew system capability, mission capability, and cost information necessary for resolving the feasibility issue. The assessment process, carried out in a full-scale three dimensional mockup of the tanker flight deck, determined that there were desirable and undesirable characteristics of all three designs. These mockup results were used to develop a fourth "composite" configuration, attempting to specify an optimum system: the most capability for the best price. The composite configuration was evaluated in a full mission simulation lasting three months. Each crew participated for a total of 60 hours spent in ground school training learning the new systems and procedures, practicing flying the simulator, and data collection. Data collection sessions required that the crews fly the airplane, rendezvous with various types of receivers and offload fuel during representative mission profiles, perform mission

communications (ATC, receivers, etc.) and accomplish cockpit procedures and checklists. The simulation work validated the acceptability of the composite design. A consensus was reached among the participating crew members that it was feasible for the reduced crew complement to complete all tasks and perform the SAC KC-135 tanker mission if the capabilities represented in the composite design were provided.

SECTION I

INTRODUCTION

This report documents the second and final phase of the Tanker Avionics and Aircrew Complement Evaluation (TAACE) Program, a three year mockup and simulation effort performed to help determine the feasibility of operating the SAC KC-135 tanker with a crew of three -- pilot, co-pilot, and boom operator.

The first phase of the program, identified as Phase 0, was conducted from June 78 to May 79. It consisted of mission analysis and mockup activities, and resulted in the identification of crew system concepts that appeared capable of providing the reduced crew complement with the necessary control and display capability to successfully complete the tanker mission. A specific crew station concept, defined in terms of equipment capabilities, equipment location, operating procedures and crew duties, resulted from Phase 0, and is documented in AFWAL-TR-80-3030, Volumes I, II, and III.

The second phase of the TAACE Program, identified as "Phase 1, Simulation," in the KC/C-135 Avionics Modernization Program, Program Management Plan, 24 April 1978, and documented herein, validated the results of Phase 0. A full-mission simulation of the above mentioned crew station was conducted, resulting in confirmation of the mockup work -- the KC-135, with the flight deck updated, reconfigured and crew duties appropriately reallocated, could be manned by a pilot, co-pilot, and boom operator, and successfully and safely accomplish all required mission tasks.

The remaining sections of this report document the program. Section II discusses some of the major features of the composite design, Section III describes the development of the simulation facility and data collection procedures, Section IV summarizes the results of the simulation flying and Section V draws conclusions from the results.

SECTION II

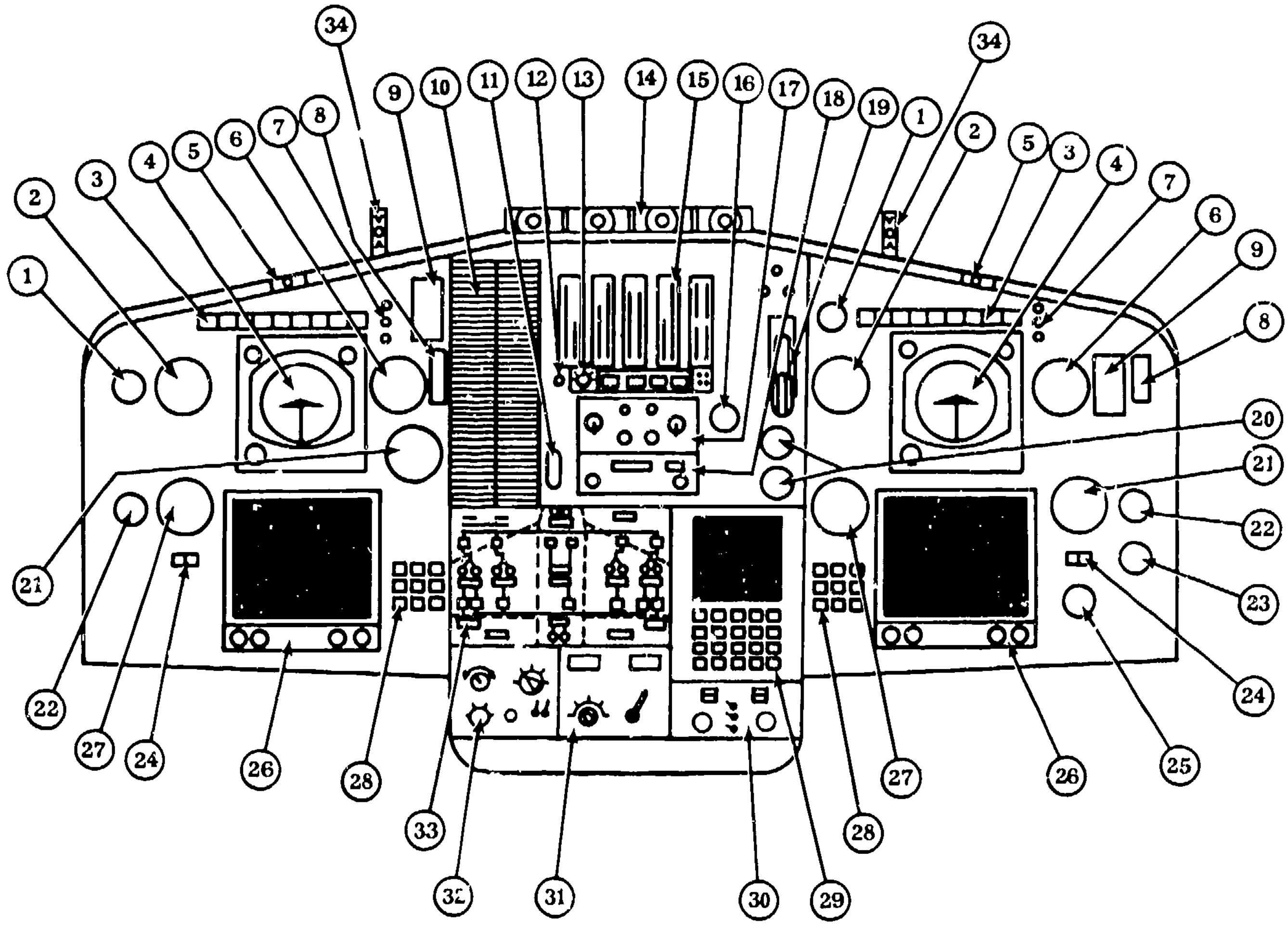
OVERVIEW OF NEW COMPOSITE DESIGN

The composite design is a significant departure from the existing KC-135 system. Major, new cockpit control and display subsystems are added; old equipment is removed; and important changes are made to crew member responsibilities. This section discusses the highlights of the composite design: features that were felt to be of particular significance for providing the three person crew with the capabilities needed to complete the mission. A complete description of the system is found in AFWAL-TR-80-3030, Volume I: Results (Ref 1). The discussion in this section is broken down into three parts: the flight deck, the boom operator's stations and crew duties.

A. Flight Deck Changes (Figures 1, 2, 3, and 4)

Probably the most dramatic change to the cockpit is the replacement of the electro-mechanical Horizontal Situation Indicator (HSI) with a cathode-ray tube (CRT) multi-purpose display (MPD), (Fig. 1, #26). This device was substituted for the old HSI because it has the flexibility to present different information at different times, in some cases information only available to the navigator in the present KC-135. Presented on the MPD in addition to horizontal situation data, is radar information (beacon, ground map, weather), flight plan routing with map annotation, and rendezvous guidance. This data is selected for presentation through the activation of switches located adjacent to the display. The pilot and copilot's systems have duplicate capabilities.

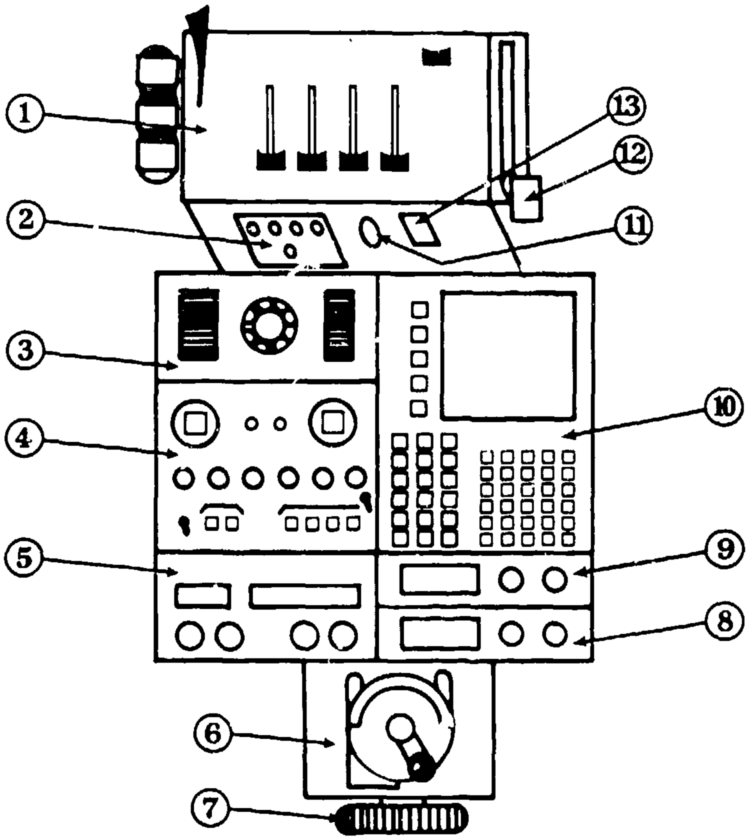
The MPD's are actually part of a larger control and display subsystem that includes another major cockpit device, the Navigation Management Control Display Unit (CDU). Two of these are located on the flight deck, both on the center console - one forward of the throttles, on the right-hand side (Fig. 1, #29); the other aft



* 1) Angle of attack indicator (copilot's location unchanged)
\# 2) Mach/airspeed indicator
3) FD-109 annunciator lights
4) Attitude director indicator
\+ 5) Master caution light
6) Altimeter
\+ 7) Marker beacon lights
\+ 8) Altitude alert lights
\+ 9) Radio altimeter
\+ 10) Caution/warning panel
* 11) Cabin pressure emergency release
\+ 12) Thrust mgt system control
\+ 13) Engine instrument digital readouts and selector
14) Engine fire switches
\# 15) Engine instruments
* 16) Hydraulic quantity indicator
\+ 17) Altitude alert control panel
* 18) Water injection panel
19) Landing gear lever
20) Flap position indicators
21) Vertical velocity indicator
* 22) Clock (also added for copilot)
23) Outside air temperature gauge
\+ 24) INS/AHRS select switch
25) Cabin pressure indicator
\# 26) HSD/MPD
\+ 27) BDHI
\+ 28) HSD mode selector switches
\+ 29) Nav mgt control/display unit #1
\+ 30) INS mode control panel
\+ 31) Radar cursor and doppler controls
\+ 32) AHRS
\# 33) Fuel control panel
\+ 34) AOA Indexer

\+ New hardware, new location
\# New hardware, current tanker location
* Current tanker hardware, new location

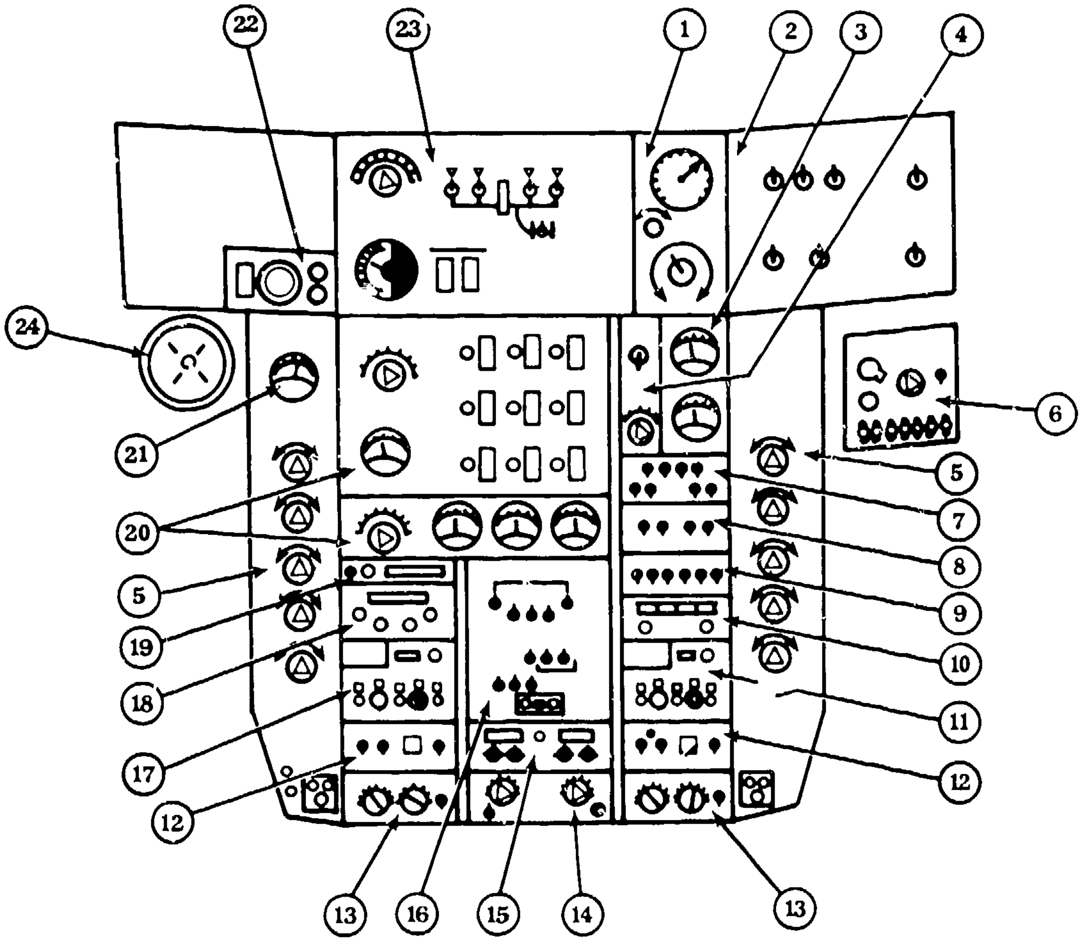
Figure 1. Front And Forward Center Instrument Panels



	1) Throttle quadrant	+	8) TACAN #1 control panel
*	2) Engine start switches	+	9) TACAN #2 control panel
*	3) Autopilot controller	+	10) Nav mgt control/display unit #2
*	4) IFF/SIF control panel	*	11) Gear horn cutout swithc
+	5) ADF control panel	*	12) Wing flap control
*	6) Rudder trim	*	13) Rudder power cutout switch
*	7) Aileron trim		

\+ New hardware, new location
* Current tanker hardware, new location

Figure 2. Aft Center Console

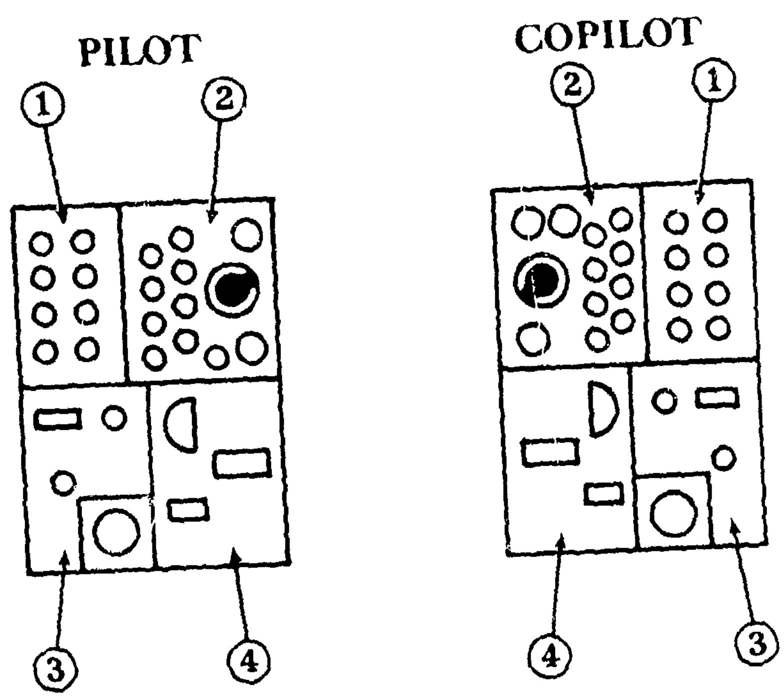


1) Cabin pressure controllers
2) Light control panel (exterior)
* 3) Volts and cycles indicators
* 4) External power control
5) Light control panel (interior)
* 6) APN-69 beacon control panel
+ 7) Hydraulic control panel
+ 8) Instrument power control panel
+ 9) Anti-ice control panel
+ 10) VHF comm control panel
11) UHF #2 comm control panel
12) Rotation go-around control panel
13) Flight director control panel
+ 14) Radar control panel
* 15) VHF nav #1 & #2 control panel
16) Autopilot control panel
17) UHF #1 comm control panel
* 18) HF comm control panel
+ 19) Warning bell, loudspeaker, and TACAN antenna control panel
20) Electrical control panel
21) Battery charging ammeter
* 22) Radar pressurization control panel
23) Air-conditioning control panel
24) Speaker

+ New hardware, new location
* Current tanker hardware, new location

NOTE: Nacelle illumination switch added to 2).

Figure 3. Overhead Panel



\# 1) Nav monitor panel
\# 2) AIC-18
3) Oxygen hose, dimmer, oxygen quantity, lamp receptacle
4) Oxygen regulator

\# New hardware, current tanker location

Figure 4. Side Panels

of the throttles, also on the right-hand side, (Fig. 2, #10). Like the MPD's, these units have the same capabilities and can be operated simultaneously. Their primary function is mission planning. After insertion of the proper information by the crew (waypoint coordinates, temperature, forecast winds, field elevation, planned fuel off-loads, flight planned altitudes, alternates, aircraft weight, etc.) the computer, to which the CDU's talk, computes ETS's, fuel required/remaining at waypoints, optimum EPR settings for crew selected profiles and much other data that is not computed manually by either the pilots, navigator, or boom operator.

The advanced navigation capabilities provided by the MPD/CDU computer subsystem were thought to embody the heart of a system that would permit the removal of the navigator crew position. Other major changes were made to either physically accommodate the MPD's and CDU's or logically complete the crew system integration started by the MPD's and CDU's.

In the first category (a change made to accommodate the CDU's) is the new fuel panel, (Fig. 1, #33). Although very similar in capability to the present system, the new device differs dramatically in appearance. The fuel flow lines illuminate as a function of valve and pump activation; a CG display is provided; fuel quantity is presented digitally; and there are several caution and warning lights installed associated with varying amounts of fuel remaining.

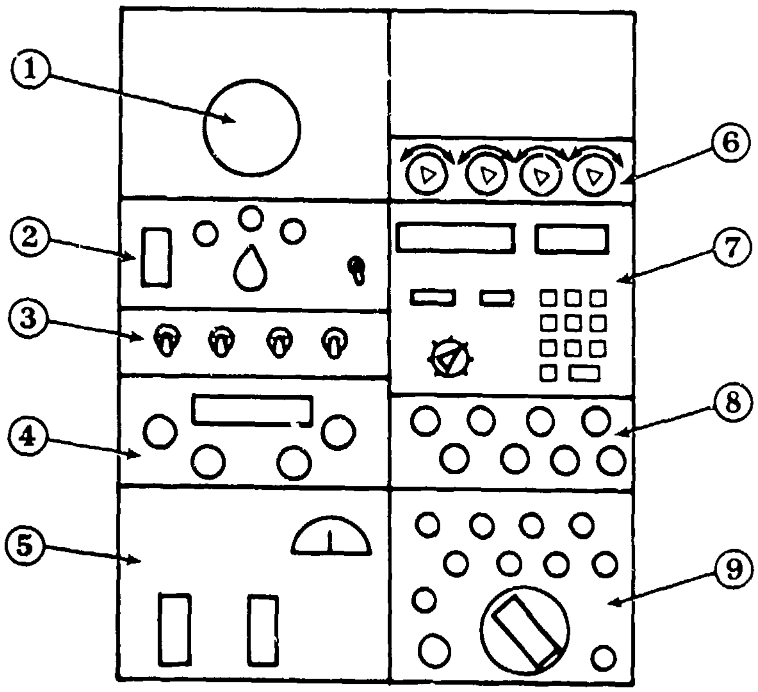
In the second category (continued integration) is the vertical-scale engine instruments and fuel management system. The vertical-scale instruments (Fig. 1, #15) take up less instrument panel space, and incorporate hydraulic pressure and quantity gauges as well. This configuration makes it possible for the copilot to monitor hydraulic system performance more completely than before and co-locates similar information (quantities, pressures, rates) in a centralized position. Also, the vertical-scale instruments are used to indicate an EPR value to be flown in order to achieve a selected fuel conservation profile generated by the computer subsystem.

Without the navigator on-board, a requirement was felt to exist to improve the monitoring of subsystem performance. Thus, another major modification is the installation of an integrated caution and warning system like that found in many Air Force aircraft (Fig 1, #10). It provides for centralized annunciation of system failures (as well as selected subsystem operating conditions that are not failures) that in the current tanker are either not annunciated at all, or are annunciated through lights or other devices scattered throughout the cockpit. Coupled with the master caution lights located on the glare shield in front of each pilot, this system was thought to provide for the required systems monitoring.

Finally, there were a series of modifications made so as to place all critical equipment within arm's reach of at least one pilot. In some cases, this required a simple relocating of hardware; more extensive modifications involved the widening of the aisle-stand aft of the throttles to accommodate additional control heads that must be accessable to both pilots.

B. <u>Boom Operator's Stations</u> (Figures 5 & 6)

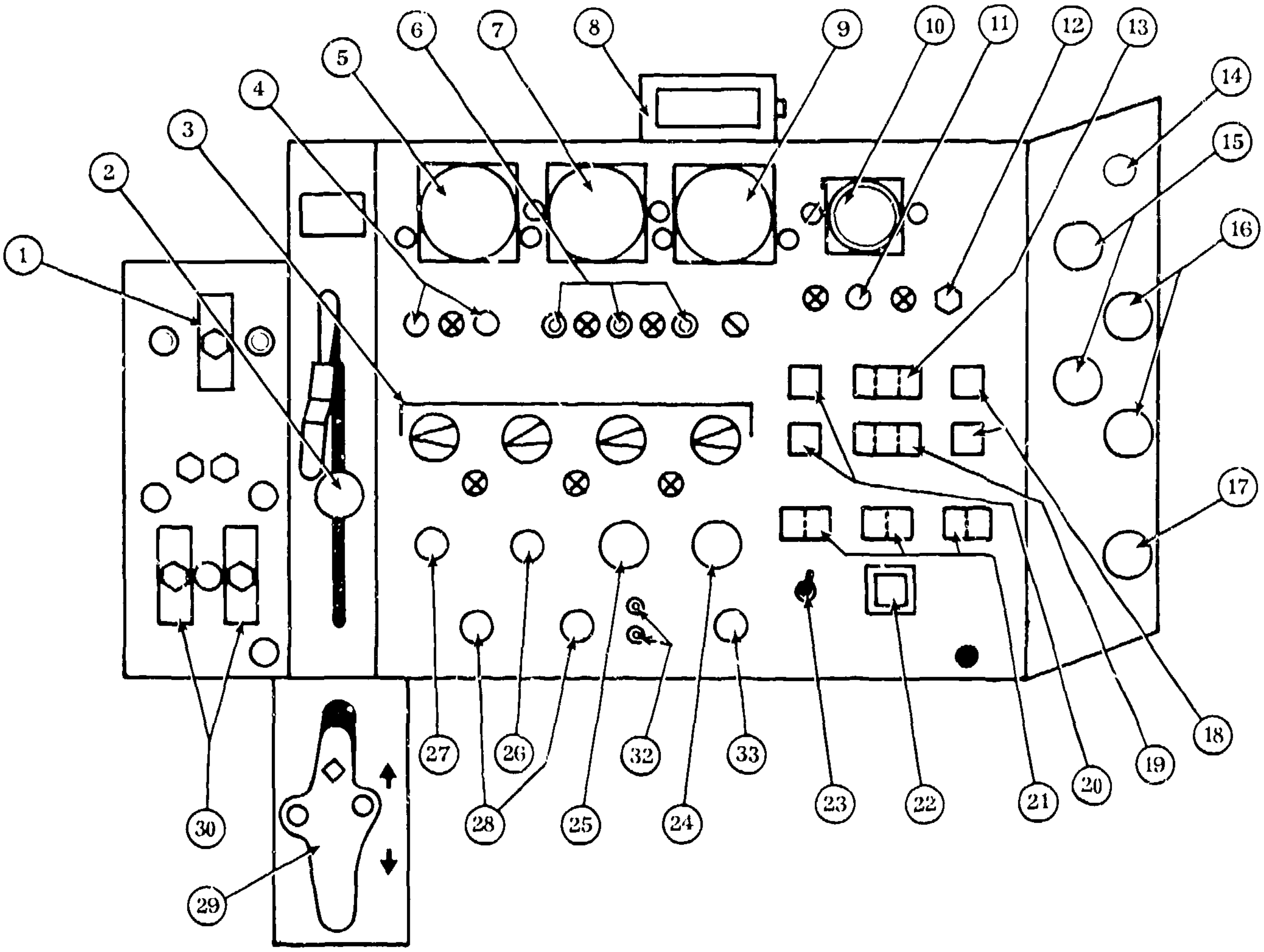
Modifications, resulting in two different designs, were made in order to improve the efficiency of fuel off-load from the point of view of both the boom operator and the flight deck. Included in both upgrades were two fuel totalizer gauges: one for total fuel off-loaded per mission, (Fig. 6, #13), the other for total fuel off-loaded per receiver, (Fig. 6, #8). Although relatively modest, this change was thought to have the potential of greatly reducing boom operator workload -- currently, the boom operator has the responsibility for keeping track, manually with paper and pencil, of all fuel off-loaded while minimizing interphone chatter. In addition, upgrade number two included an automatic visual off-load system designed



* 1) Accelerometer
* 2) Ciphony control panel
\+ 3) HF transfer and INS selector switches
* 4) HF comm control panel
\+ 5) Oxygen control panel
\+ 6) Light controls
\+ 7) INS control/display unit
\+ 8) Nav monitor panel
\+ 9) AIC-18

\+ New hardware, new location
* Current tanker hardware, new location

Figure 5. Boom Operator's Forward Station



1) Emergency override switch
2) Boom hoist lever
3) Pilot director lights controls
4) A/R system test/reset switches
5) Azimuth indicator
6) Contact signal lights
7) Telescoping indicator
+ 8) Fuel transfer indicator (per receiver)
9) Elevation indicator
10) Signal coil
11) Signal coil test switch
12) A/R master switch
+ 13) Fuel transfer indicator (per mission)
14) Window defrost switch
* 15) Nacelle illum controls
16) Panel lights controls
17) Compartment lights controls
+ 18) Aft body pump switches
+ 19) Fuel flow indicator
+ 20) Forward body pump switches
+ 21) Fuel quantity gauges
+ 22) Offload selector
+ 23) Auto/manual select switch
24) Boom nozzle illum control
25) Under body illum control
26) Underwing illum.
27) Telescope at disconnect switch
* 28) Boom marking illum controls
# 29) Boom telescope lever
30) Ground test switches
31) Pilot director lights switches
32) Restart indicator light

+ New hardware, new location
# New hardware, current tanker location
* Current tanker hardware, new location

NOTE: Items 2 and 23 for upgrade configuration #2 only

Figure 6. Boom Operator's Aft Station

so that the boom operator could spend more time in full contact with the receivers, while simultaneously relieving the copilot of some fuel panel monitoring tasks. Upgrade number one did not have this capability.

C. Crew Duties

The equipment changes were not sufficient by themselves to accommodate the removal of the navigator crew position. There are tasks that the navigator performs, such as altitude call-outs on final approach, that were not replaced with new hardware. Thus, crew member responsibilities, including checklists and formal operating procedures, were also modified. One of the most significant of these is the designation of the boom operator as a Positive Control crew member. The composite design requires that the boom operator copy and acknowledge launch and enroute messages, monitor the HF radio when not in the boom pod, and in general play a much more integrated role in the functioning of the vehicle. Also changed is the copilot's role: he has greatly increased responsibilities for aircraft navigation and position awareness. Finally, since radar information is now displayed on the MPD's, both pilots must be proficient in interpreting radar returns, as well as navigating by radar mapping.

Volume I of AFWAL-TR-80-3030, as mentioned earlier, details the specifics of the composite design.

SECTION III

EVALUATION PREPARATION

It was the intent of the work documented herein to validate the crew system concepts embodied in the composite design. The process started with the development of the simulation capability involving several major activities, including preparation of the simulator, and development of experimental procedures.

A. Simulator Preparation

1. Pilot/Copilot Station

All crew station equipment, (panels, controls, display, etc.) were either fabricated in-house or closely approximated with off-the-shelf avionics hardware representing the desired capability. The panels, consoles, and cockpit equipment were installed in the Flight Dynamics Lab's KC-135/Boeing 707 type simulator. A KC-135 aero model was developed to simulate aero-dynamic control of aircraft pitch, roll, yaw, longitudinal velocity, lateral velocity and vertical velocity. Environmental conditions of day, night and engine sound were simulated along with a visual presentation for airport departures/arrivals. Also, a presentation of land mass features for radar ground mapping was simulated. Software programs were developed to support flight simulation and to support the integration and operation of the various mission systems. The flight deck was equipped with standard KC-135 yoke and rudder controls, nosewheel steering and Boeing 707 type throttle quadrant. Motion was not used for this simulation. The simulator cab seating arrangement consisted of two standard pilot seats and a modified boom operator's seat mounted on rails so that the seat could be positioned between the pilots' seats (behind the aisle stand) or positioned at the forward boom station (the present navigator's station). A pilot observer was stationed behind the pilot's seat and an experimenter was stationed behind the pilot observer. (Figure 7).

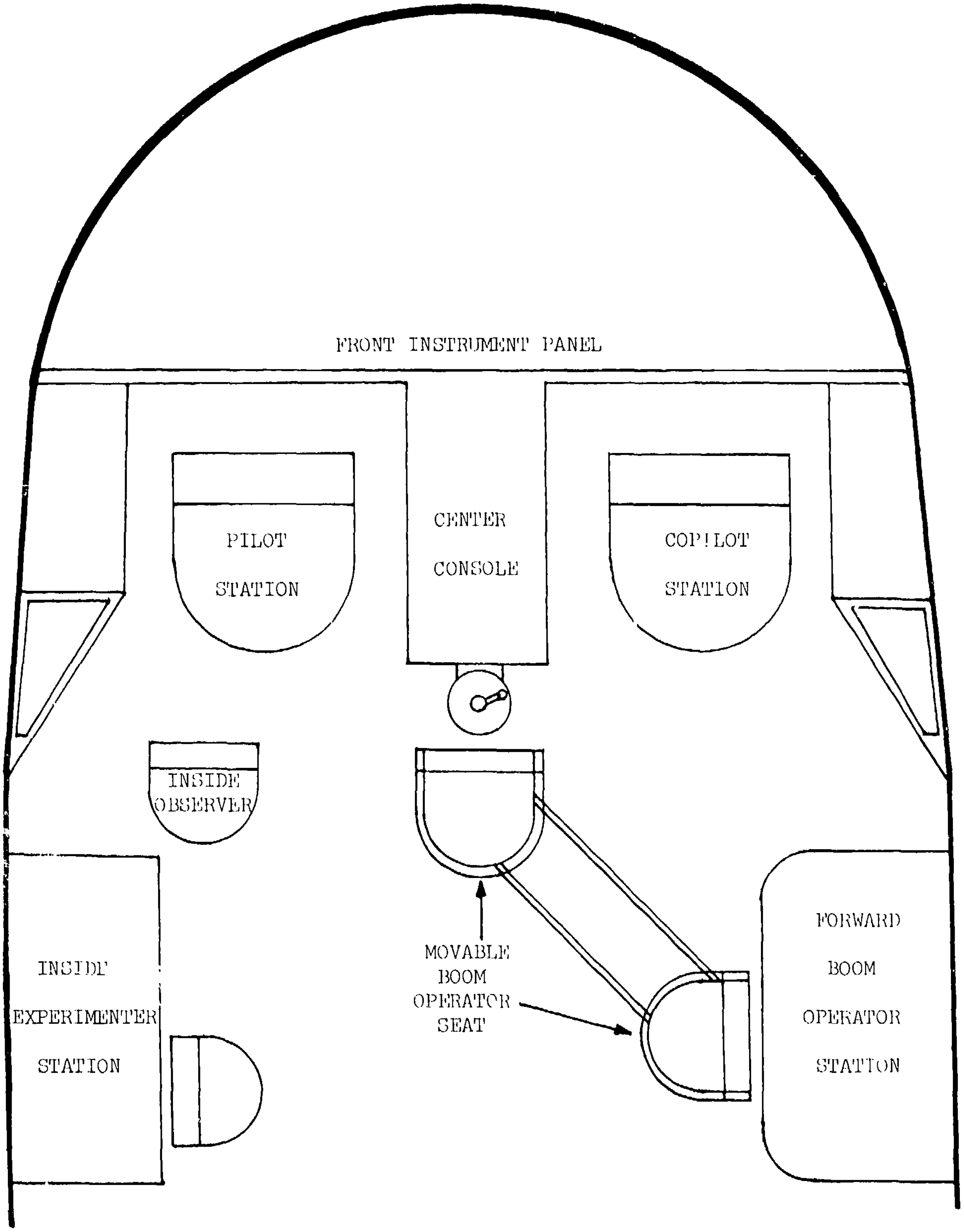


Figure 7. TAACE KC-135 Simulator Cockpit Layout

2. Boom Operator's Station

The aft boom operator station was located at a separate console outside the cab. It was equipped with several dynamic controls and displays including a boom telescope lever, a ruddervator control stick, a receiver display, a fuel control/display panel and a communication system, (Figure 8).

The simulation was supported by a separate computer deck with multiple computer systems, by a separate radar land mass simulator and by a Redifon/Duoview visual facility. The visual system provided outside visual cues for only the takeoff and landing phase of simulation flying (up to approximately 1500' AGL).

3. Experimenters' Stations

Six experimenter stations were needed to conduct the flying sessions. Each was equipped with AIC-18 intercomm units which could monitor the subject aircrew communications as well as provide for private channel communications between experimenters. The six stations were located inside the cab, outside the cab and in an adjacent room which housed the computer systems that supported simulation. The experimenter's station inside the cab was equipped with controls for initiating system malfunctions and a unit to control a workload measurement experiment. The experimenter's station outside the cab was a large console equipped with a communication monitoring panel and 5 video monitors. The communication monitoring panel displayed all frequencies selected by the subjects, (including IFF codes), and the transmitter selected for broadcast. The video monitors repeated the cockpit pilot and copilot multipurpose HSD selections, the cockpit mission management display selections, cockpit activities, and the boom operator receiver and boom position display. The receiver's position on the boom operator's display and the receiver's maneuvers to pre-contact, contact and disconnect were also controlled from the outside experimenter's station. The

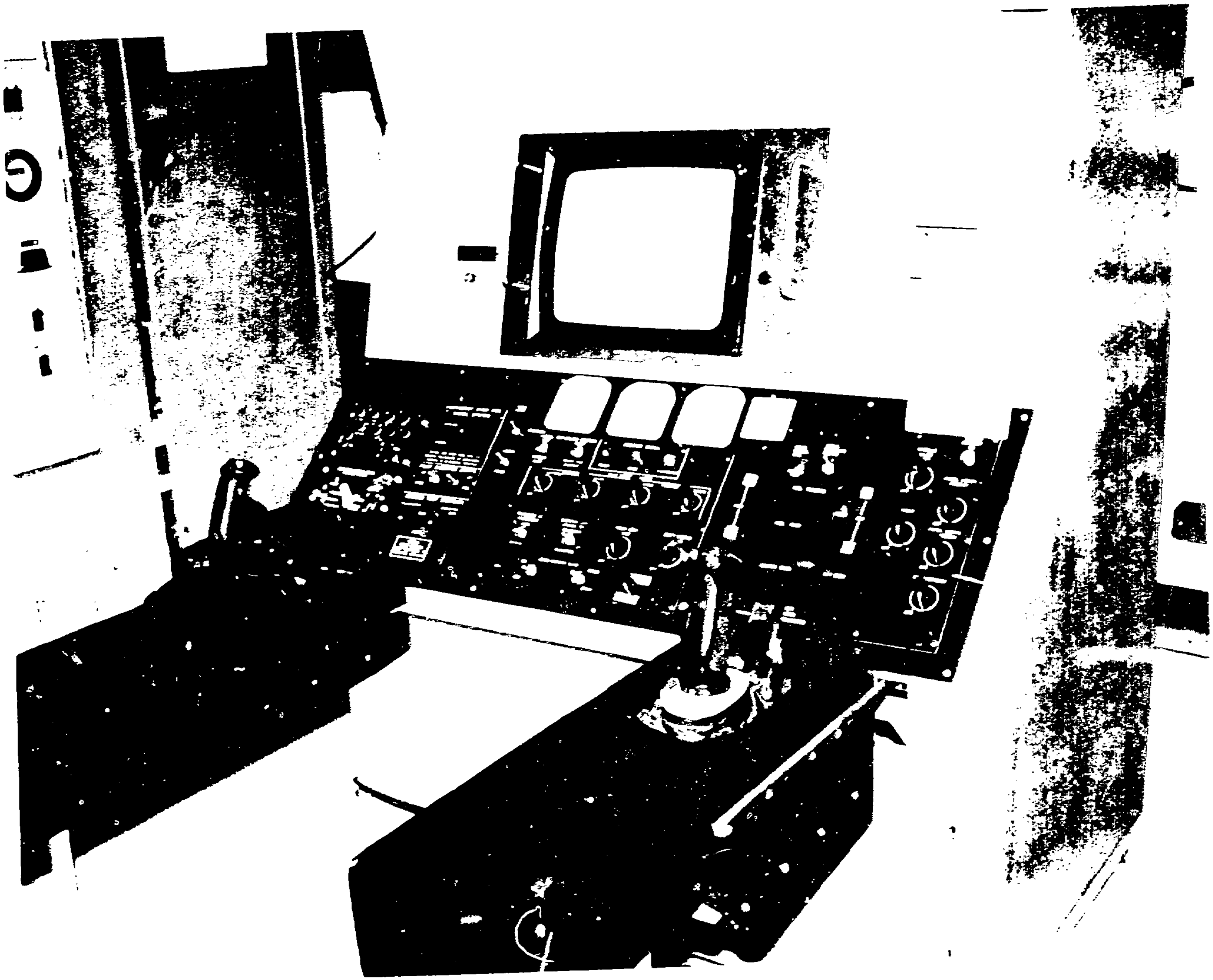


Figure 5. TAATE [illegible]

other experimenter stations were Intercomm positions used for maintaining coordination among the project people responsible for the computer complex, radar simulation and visual system.

B. Experimental Procedures

1. Specific Research Issues

The Phase O mockup activities suggested that the crew workload associated with managing the various subsystems was sufficiently low to permit safe accomplishment of the mission. However, with no flying task required of the pilots, the mockup exercise did not explore the compounded workload of both flying the vehicle and operating the other cockpit systems. In a sense, the mockup evaluation crews were not "distracted" by the flying task, and thus were able to concentrate on the management of the various subsystems. The mockup evaluation was, therefore, a biased assessment of the different crew station concepts being examined. This bias was of particular concern in three areas: the useability of the CRT displays (the HSD's and Nav Management CDU's) the effect on crew workload of an auto-pilot failure, and the usefulness of an updated boom operator's station. In order to more fully explore these areas, three specific research issues were identified.

a. Utility of Horizontal Situation and Navigation Management display formats and switching.

Although reach, accessability, viewability, and other anthropometric characteristics can easily be assessed in a mockup, the dynamic characteristics of displays cannot. Thus, particular emphasis was placed on examining the pictures presented on the cockpit CRT's.

b. Effect on crew workload of an in-operative auto-pilot.

With a functioning auto-pilot, the simulation exercise becomes somewhat similar to the mockup study - little or no flying tasks required. Thus, it was reasonable to fail the auto-pilot and require the crew to complete the mission under that condition. Of concern, once again, was the ability of the crew to complete all necessary tasks without the navigator -- his removal results in one less set of eyes to scan for traffic or system malfunctions; one less crew member to help maintain position awareness or compute needed information.

c. Value of an updated aft boom station.

The results of Phase 0 suggested that some improvement could productively be made to the aft boom station, giving the boom operator more capability to control the off-load while improving his ability to monitor the position of the receiver. Therefore, several different updates were "flown" during the simulation evaluation to assess the value of alternative concepts.

2. Experimental Design

In order to provide an unbiased assessment of the design, a plan was established for data collection in the simulator that would permit an orderly presentation of design concepts and alternatives. This plan or experimental design determined, before data collection began, the specific set of conditions each crew would experience during their flying sessions. Four different variables (the three specific research issues plus mission type) were manipulated so as to conduct a balanced experiment exposing each of the crews to all conditions. The four variables and how they were combined for each crew's flying session is given in Table 1. The matrix shows that every crew flew three flights (DATA SESSIONS) and that during these flights (either an EWO, CONTINGENCY OR DEPLOYMENT mission) both Nav management CDU's were on or one of the two was off, the auto-pilot was on or off, and the boom station was configured as either the baseline tanker or one of two updates.

These variables were picked to ensure simulation activities that, by exposing

TABLE 1

EXPERIMENTAL DESIGN MATRIX

DATA SESSION	CREW NUMBER	INDEPENDENT VARIABLES			
		MISSION SEGMENT	NAV MANAGEMENT CDU STATUS	*AUTO-PILOT STATUS	BOOM STATION CONFIGRUATION
#1	1	EWO	#2 Off	AP $\rightarrow$ $\overline{AP}$	BASELINE
	2	DEPLOYMENT	#1 Off	AP $\rightarrow$ $\overline{AP}$	UPDATE #1
	3	CONTINGENCY	BOTH ON	AP $\rightarrow$ $\overline{AP}$	UPDATE #2
	4	CONTINGENCY	#1 Off	AP $\rightarrow$ $\overline{AP}$	BASELINE
#2	1	CONTINGENCY	#1 Off	$\overline{AP}$ $\rightarrow$ AP	UPDATE #1
	2	EWO	BOTH ON	$\overline{AP}$ $\rightarrow$ AP	UPDATE #2
	3	DEPLOYMENT	#2 Off	$\overline{AP}$ $\rightarrow$ AP	BASELINE
	4	EWO	#2 Off	$\overline{AP}$ $\rightarrow$ AP	UPDATE #1
#3	1	DEPLOYMENT	BOTH ON	AP $\rightarrow$ $\overline{AP}$	UPDATE #2
	2	CONTINGENCY	#2 Off	$\overline{AP}$ $\rightarrow$ AP	BASELINE
	3	EWO	#1 Off	AP $\rightarrow$ $\overline{AP}$	UPDATE #1
	4	DEPLOYMENT	BOTH ON	$\overline{AP}$ $\rightarrow$ AP	UPDATE #2

*AP $\overline{AP}$: Autopilot operating during 1st half of the mission, not operating during 2nd half of the mission.

$\overline{AP}$ AP: Autopilot not operating during 1st half of the mission, operating during 2nd half of the mission.

the crew members to equipment concepts, cockpit procedures and varied operational conditions, would permit an "in mission context" examination of the specific design issues discussed earlier. Thus, a simulation flight with one of the CDU's turned on or off would permit the crew to assess the value of that system and force them to deal with its operation; with the auto-pilot turned on or off, to deal with systems management as well as flying the airplane; with the different boom station configurations, to assess boom operator and copilot workload.

3. Evaluation Procedures

All four aircrews, consisting of a pilot, copilot and a boom operator, went through the same process, scheduled to take 7 days. The average experience of the pilots was 988 hours in the KC-135 and 1763 hours total. The copilots average experience was 195 hours in the KC-135 and 903 hours total. The boom operators average experience was 712 hours in both the KC-135 and in total time.

TABLE 2

AIRCREW FLYING HOURS

		KC-135	TOTAL
CREW 1	P	1000	1650
	CP	100	350
	BO	1647	1647
CREW 2	P	1200	1500
	CP	180	430
	BO	600	600
CREW 3	P	1150	1400
	CP	100	350
	BO	350	350
CREW 4	P	600	2500
	CP	400	2480
	BO	250	250

The following is a general description of their activities:

Day 1. Ground school covering all modified crew systems except the mission management and horizontal situation display systems.

Day 2. Ground school training on the mission management and HSD systems.

Day 3. Systems review and mission briefing for practice traffic patterns. Each pilot flew four daytime and two nighttime traffic patterns with landings for simulator handling qualities familiarity.

Day 4. Two cross country training missions -- The first was a round robin out of Loring AFB flown primarily for familiarization with all updated aircrew systems, especially navigation. The second mission was a cross country training flight from London Gatwick to RAF Mildenhall. Rendezvous and fuel offload were practiced during this mission.

Days 5, 6, and 7 Tanker missions for data collection -- One operational tanker mission was flown each day for crew system evaluation and data collection. The order in which the missions were flown is shown in Table 1. A narrative description of the three missions (overviewed in Figure 9), follows.

Loring Deployment - A cell of five (5) tankers depart Loring AFB on a Coronet Deployment to rendezvous over Halifax, Canada with a flight of 12 A-7Ds, performs four aerial refuelings and recovers at RAF Mildenhall (tankers) and RAF Wittering (fighters). Subject crew departs 15 minutes late due to engine water problems on takeoff. Flight plan change is required to allow subject crew to catch up. A generator failure occurs during rendezvous with tanker cell. The flight is repositioned to 30 minutes prior to refueling #3. Fighter #12, meanwhile, had minor refueling problems during the second refueling and subsequently, three of the tankers returned to Loring AFB as scheduled. Just prior to the third refueling, lead tanker loses radar. Subject aircrew in the number 2 tanker assumes cell command and responsibility while maintaining #2 tanker position. Numerous weather buildups and IMC conditions are encountered, requiring vectors from subject crew to lead tanker. During refueling #3, fighter #12 cannot receive fuel from subject

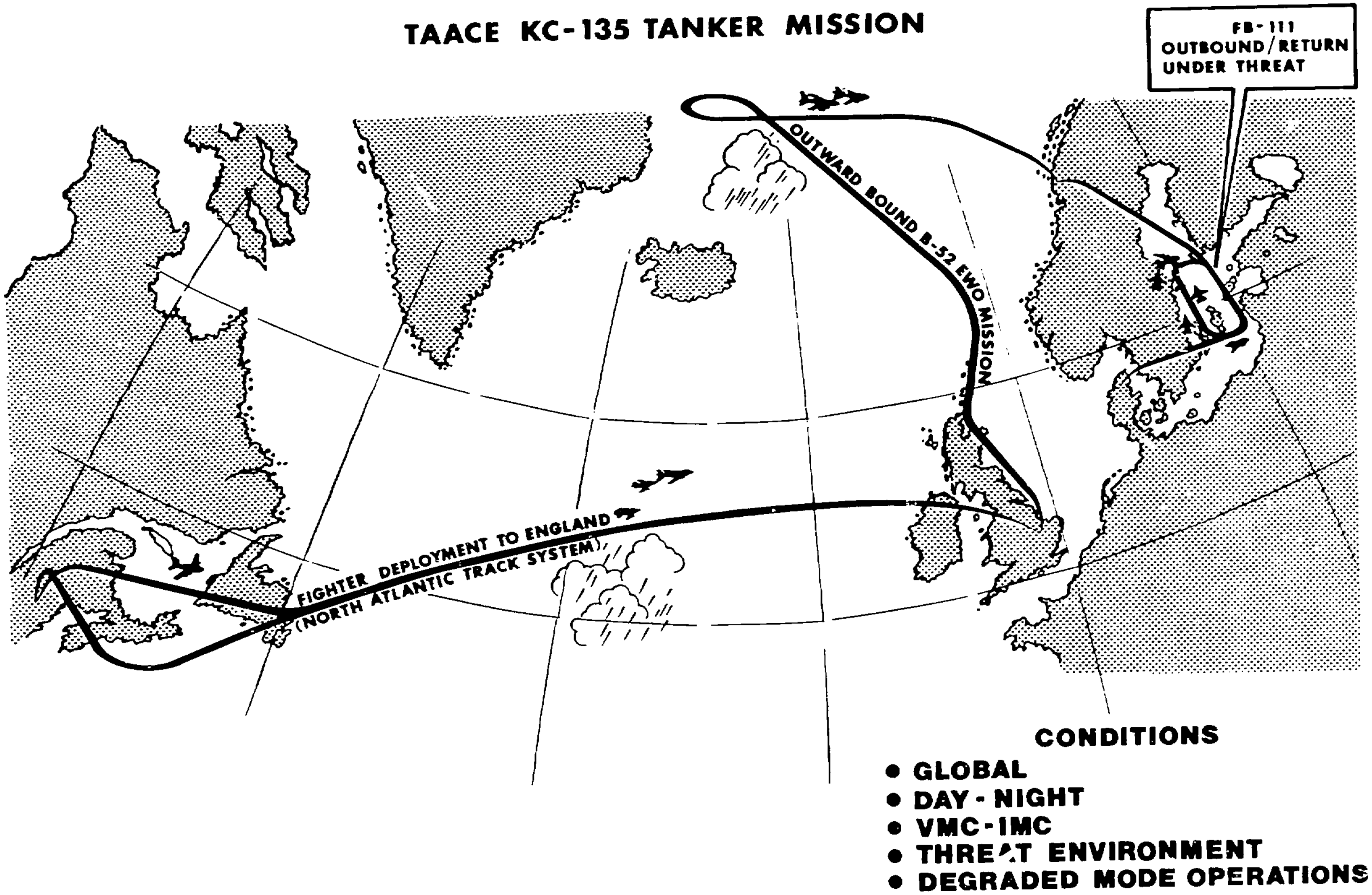


Figure 9 Mission Profile

aircrew tanker and is finally escorted to nearest landfall through coordination with "Head Dancer" (airborne assistance) and "Duckbutt" (airborne search and rescue). After this problem is resolved, the flight repositioned forward over RAF Brize Norton. Meanwhile, the fourth refueling has been completed and the cell was terminated. The subject aircrew recovers at Mildenhall RAF under minimum weather conditions.

EWO Mission - Subject aircrew is on alert and is launched as #2 on a two ship EWO mission to rendezvous with two B-52s. During launch, subject aircrew experiences a runaway stabilizer trim. After subject aircrew completes departure procedures and radar update for INS alignment (all nav aids are shut down) the flight moves forward to a position north of Scotland near Saxavord. After additional radar updates for the INS systems, lead tanker experiences engine problems and eventually experiences an engine fire that becomes uncontrollable. After lead tanker air aborts, subject aircrew is repositioned forward to 30 minutes prior to the ARCP. Weather is detected in the planned AR track, requiring a revised ARCP. The B-52 receivers request and receive all of the available fuel from the subject aircrew which leaves the subject crew with just enough fuel to make one pass at their scheduled recovery base at Bodo, Norway. The mission terminates with an airborne radar approach (nav aids are not available) at non-precision weather minimum, complicated by fuel exhaustion.

Contingency Mission - The subject aircrew is launched from Bodo, Norway as lead tanker in a two-ship cell. The mission is to set up an anchor over the Baltic Sea along the Soviet border to support random flights of NATO fighters who are engaged in a contingency action along the Soviet border. After the mission launches, the #2 tanker loses part of his mission management system. After departure procedures are completed, the mission is repositioned forward to just north Stockholm, Sweden. Subsequently, several radar updates are accomplished and the anchor pattern is entered. GCI vectors several flights of fighters in for refueling within the anchor. Weather in the anchor track becomes a problem. Minimum fuel fighters require diversion of the tanker out of the anchor. A second diversion for a minimum fuel fighter takes the subject aircrew to the Soviet border. An electromagnetic pulse (EMP) is experienced by the subject crew which leaves the boom operator blinded and the subject crew without any electronic avionics. The subject aircrew attempts to recover at Aalborg, Denmark, which terminates this mission.

a. Conduct of the Experiment

Following the ground school and simulator flight training missions, the subject aircrews flew the three previously described operational tanker missions. Prior to each flight, the crew received preflight briefings, representative of those required by SAC operating procedures. The briefings included route and receiver information, formation procedures, weather, intelligence, and primary and alternate recovery bases. Mission materials were provided for each mission, including completed flight plans, Take-off and Landing Data, weight and balance information, clearance forms and all required maps and FLIP charts. After the briefing, the crews were allowed sufficient time to study the mission and perform the required crew briefings.

At the simulator cab, the crew performed the aircraft interior checklists and all subsequent checklists, utilizing a modified KC-135 checklist which had been changed to accommodate the three-man-crew and the updated avionics.

Once the required checklists were performed, the crew launched and flew each mission, performing all required communications (ATC, formation calls and other agencies), navigation and system operations/malfunctions and associated workloads that might be encountered on the selected scenario missions (described earlier in this section).

The inside experimenter controlled the mission sequence, system malfunctions and a workload experiment. The two outside experimenters monitored mission progress and aircraft position. All communication transmissions were also monitored at the experimenter's console. Thus, the outside experimenters were able to assume the role of all outside communicators (ATC, receiver calls, command post, ground control, etc.) and control the initiation/termination of each mission segment. The experimenter inside the cab utilized a private intercomm channel to coordinate activities between the subject crew, outside experimenters and simulation system operators.

Prior to each refueling segment, the boom operator proceeded to the aft boom operation station, located outside the simulator cab. From this location he simulated refueling each receiver through radio/interphone communications, a fuel panel and a CRT tracking task symbolic of a refueling boom and a receiver aircraft. The outside experimenters controlled the pre-contact, contact and disconnect/breakaway maneuvers as well as the receivers communication. At the completion of each refueling segment, the boom operator resumed his position and crew duties inside the cockpit, reading checklists, monitoring HF, monitoring systems and simulated outside watch.

b. Data Collection

Although subjective and objective data were collected during the study, only the subjective data is presented. The objective performance data was lost during the conversion to a new computer system after the program was completed.

Questionnaires were administered to each subject at the beginning of the experiment (Day 1). Additional questionnaires were administered after each data mission was flown. At the end of the experiment, a final questionnaire was administered. Subjective data were also collected during a final debriefing of the aircrews.

c. Crew Station Criteria Update

During the initial portion of the TAACE Program, (after the Phase 0 mission analysis) a criteria document was drafted which described the capabilities required for a three-man crew (two pilots/one boom operator) to accomplish the KC-135 tanker mission. Following the mockup evaluation (Ref. 3), this criteria document was updated to reflect the results of the assessment. The criteria document reflecting the results of the simulation validation has been published as AFWAL-TR-81-3010, "KC-135 Crew System Criteria." The reader is urged to examine this document for further guidance pertaining to specific crew station design criteria for operating the KC-135 with a pilot, copilot, and boom operator.

SECTION IV

RESULTS

Results presented in this report are based on the crew member responses to opinion questionnaires administered before, during, and after the simulator flying sessions.

Questionnaires consisted of fill-in-the-blank questions, yes-no questions, and rating scale questions. There were three rating scale questions used, as shown in Table 3. Scale I "Quality Level" was used to rate the useability of information presented on a specific display or the physical location of a piece of hardware. Scale II "Workload Level" was used to establish the amount of work required to perform a specific job. Scale III "Requirement Capabilities" was used to rate either the degree of need for a certain system/concept or the degree of useability of a system/concept. For ease in completing the ratings, all three scales ran from 0, meaning "least" or "worst" to 10, meaning "most" or "best". All ratings cited in the report are averages. Citations from questions other than the rating scales are given as frequency counts, totaling the number of crew members responding.

Results of the simulation exercise are presented first as they relate to the specific research issues identified in Section III, B.1, and then as more general findings relating to features of the cockpit design.

A. Specific Research Issues

1. Horizontal Situation and Navigation Management Display Formats

a. Horizontal Situation Display

In the broadest sense, there seems to be a strong requirement for a Horizontal Situation Display. All crew members rated the requirement for an HSD as compared to the standard HSI as extremely useful and an enhancement to mission

TABLE 3

RATING SCALES USED TO RECORD PILOT OPINION

Scale I (Quality Level)

Rating	
10	Excellent
9	Very Good
8	
7	Good
6	
5	Fair, but useable
4	
3	Poor (Almost not useable)
2	
1	Very Bad
0	Unacceptable - not useable

Scale II (Workload Level)

Rating	
10	Overload
9	Extreme
8	
7	Significant
6	
5	Moderate
4	
3	Low
2	
1	Very Low
0	No work

Scale III (Requirements/Capabilities)*

Rating	
10	Would or did enhance mission performance so much as to be absolutely necessary to perform the mission.
9	Would or did enhance mission performance greatly - extremely useful. Requirement recommended.
8	
7	Would or did noticeably enhance mission performance - quite useful. Requirement partially recommended.
6	
5	Would or did enhance mission performance somewhat - useful, but not required.
4	
3	Wouldn't or didn't really enhance mission performance - only sometimes useful.
2	
1	Wouldn't or didn't enhance mission performance whatsoever- not useful.
0	Couldn't use it even if it was available.

* This scale is a continuum from an "absolute necessity" rating (10) to an "absolutely could not use it" rating (0).

performance with the majority indicating that an HSD would be absolutely necessary to accomplish the mission. The following HSD formats and controls were judged by all pilots and copilots as falling into the range of extremely useful to absolutely necessary requirements: symbol generated map, hold format, rendezvous format, HSI format, range control, and clutter/declutter control. The same held true for the following HSD information overlays: symbol map with weather, symbol map with beacon, symbol map with ground map, skin paint other aircraft in formation, and cursor update for radar. In nearly all of these, the majority response was that they enhanced mission performance so much as to be absolutely necessary to perform the mission.

When asked to rate, using Scale III, requirement that different types of information be presented on the display, the responses ranged from 8.5 to 9.75, for both pilots and copilots. Similarly, the information overlays provided during simulation were also rated a strong requirement: from 9 to 9.5 for pilots, from 9.25 to 9.5 for copilots. Additionally, the pilots felt that the amount of information displayed was generally satisfactory, giving Scale I ratings from 7 to 10. Also, the pilots seemed generally satisfied with the switch matrix provided for changing display formats; from a low of 4 (one response), to a high of 10, (2 responses) with an average rating of 8.41, (Scale I). Finally, although the pilots felt that using the HSD's for displaying radar information was good (from 7 to 10 with an average rating of 9.5 using Scale III) they identified radar monitoring and control as one of the tasks that posed a problem. This is discussed further in Section V.

b. <u>Navigation Management Display Unit and Formats</u>

As they did for the HSD, the pilot's strongly favored having a Navigation Management System on the airplane. It was almost rated as mandatory equipment with an average value of 9 for the Scale III ratings. In addition, the specific pages presented on the display were generally considered as "GOOD" (Scale I) with just about the right amount of information being provided. The exception to the otherwise high ratings were those for the Fuel Page; although it was thought to be nearly a requirement, it was also thought to present an excessive amount of information. These ratings, like those for the HSD's, were consistent across missions and crew position (pilot, copilot) suggesting fairly stable information requirements, regardless of specific mission type.

2. Pilot/Copilot Workload - Auto-Pilot

Many questions were asked dealing with the crew workload in an attempt to determine how it was effected by the different avionics capabilities included in the design. Obviously, there is a very complex interaction among the various elements of the design and the workload experienced by the crew. For example, it may be the case that with all systems operational, crew member reported workloads are well within acceptable limits. However, with different types of equipment out of order, workload levels may change, certainly affecting the crew members acceptance of the system, perhaps also their ability to do the job. In the TAACE Program simulation, the combined influences of three major design features on crew workload were examined; auto-pilot availability, navigation management system availability and boom operator station design.

In general, crew workloads were such as to permit successful accomplishment of the mission. This was true for all tested combinations of the above mentioned variables. Whether the auto-pilot was ON or OFF, or whether it was OFF in combination with the baseline boom station, or whether both navigation management control-display units were ON or one was OFF seemed to make little difference to the crews - they felt the mission could be successfully completed. Out of a total of 192 responses to questions asking specifically if the mission could be completed less than 3% were negative.

Overall workload to fly each of the three missions was rated as slightly higher than what the crew members would expect to encounter flying the same missions in the baseline KC-135; nevertheless, they all felt that even a minimally experienced crew, given the capabilities of the composite design, could complete the mission.

In general, pilots responded that the greatest percentage of total workload for each mission involved piloting tasks, followed by communication, navigation, and aerial refueling tasks. Paperwork and other miscellaneous tasks were seen to consume very little of the pilots' time. When required to rate the workload level itself for these tasks, piloting, aerial refueling, and communications were tasks demanding a slightly more than moderate level of workload; navigation tasks required a slightly less than moderate level of workload; and paperwork and other tasks required low or very low levels. There was little variation among each pilot's workload ratings for the various mission phases across the three mission. As expected, departure, aerial refueling, descent, and approach and landing were the areas of greatest workload while climb and cruise were much less so.

In most cases, the copilot's questionnaire data agreed with that of the pilot's. Copilot responses showed that when compared to the workload level as it stands in the tanker today, utilizing the crew systems evaluated during simulation represented somewhere between a slight and moderate increase in workload for them. However, they unanimously agreed that regardless of the particular mission segment, a minimally experienced pilot and copilot could successfully accomplish that mission with the crew station. When asked to rate their own workload level needed to monitor fuel flow and fuel quantity information, the copilots placed that workload at a moderate level -- only slightly higher than the pilots' perception of the copilots' workload.

Regardless of mission, the copilots indicated that navigation and communication tasks consumed most of their time while aerial refueling, piloting, "other", and paperwork tasks were less demanding. When they were required to rate the workload level necessary to perform those tasks, navigation, communication, and aerial refueling tasks were shown to demand a slightly more than moderate level of workload while "other" tasks, paperwork, and piloting required only low to moderate levels. As did the pilots, the copilots generally rated their workload levels for departure, climb, cruise, aerial refueling, descent, and approach and landing consistently across the three missions and results showed that aerial refueling tasks generated "significant" workload levels while departure, approach/landing, and descent phases generated moderate levels. Climb and cruise segments were rated as low to moderate.

3. Boom Station Upgrade

All crew members were asked a series of questions to determine not only the need for improved boom station controls and displays but also the value of "upgrading" the boom operator's job; increasing boom operator responsibility for communications monitoring, message coding and decoding and adding new cockpit duties to be exercised by the boom operator while on the flight deck.

a. Pilot/Copilot Data

All pilots thought that with an upgraded boom operator, even with one pilot incapacitated, all three missions could be performed. Only two pilots, however, thought all three missions could be performed under similar circumstances with a non-upgraded boom operator. In either event, all pilots thought the aircraft could be returned home safely without the upgraded boom operator. With an upgraded boom operator, the pilots believed that they could accomplish any of the mission segments with or without an auto-pilot and with only one of the navigation management displays operating.

Pilots favorably rated the requirement for aft boom station transfer fuel flow rate and totalizer, and an aircraft fuel flow totalizer, emphasizing that by providing those displays to the boom operators their own workload would be significantly reduced. Regardless of mission segment, they highly recommended the computerization of weight and balance, and takeoff and landing data calculations. Finally, there was wide variation in opinion on the effect an emergency boom hoist would have on mission accomplishment with a 3-man flight deck crew -- primarily, they said they would not have been overworked for the time that the copilots left their station but were unsure as to whether mission safety would be jeopardized.

The copilots were not quite so favorable as were the pilots in their ratings of the requirement for aft boom station transfer fuel flow rate and totalizer gauges and an aircraft fuel flow totalizer. They were not convinced that such devices helped to reduce their own workload. Like the pilots, the copilots highly recommended the computerization of weight and balance and takeoff and landing data calculations. Finally, the copilots disagreed with the pilots on the effect an emergency boom hoist would have on mission accomplishment with a 3-man flight deck crew; the data indicated they felt that the pilot would have been significantly overworked for that time but that mission safety would not be in jeopardy.

The copilots seemed to agree with the pilots that with an upgraded boom operator, a 3-man crew -- even in the case of incapacitation of one pilot -- could accomplish all the missions and fly the aircraft home safely. However, if the boom operator were not upgraded, although the aircraft could be returned home safely, mission success was questionable.

b. Boom Operator Data

Almost unanimously for all boom operators across all mission segments, there was sufficient time to perform "see and avoid" duties while carrying out other designated tasks. The capabilities presented in the cockpit and boom station design were rated as being extremely useful and an enhancement to mission performance. There was widespread agreement that, regardless of mission segment, communication and aerial refueling tasks demanded the highest percentage of total time, followed closely by "see and avoid" duties and systems monitoring. Navigation tasks, paperwork, fuel management, and weight and balance computations consumed much less time. When asked to rate the workload level required to accomplish these tasks, the boom operators rated air refueling, systems monitoring, and see and avoid as moderate to significant workload generators; navigation, communication, paperwork, and fuel management tasks as moderate workload items; and weight and balance computations as a very low workload item.

The boom operators felt that a 2 pilot/1 boom operator crew could safely and adequately perform the missions. However, the general opinion seemed to be that when transfer fuel flow rate and totalizers, air refueling pump indicators and tank quantity gauges were provided at the aft boom station, the boom operators' workload increased, safety was jeopardized, and aerial refueling procedures were made more complicated when compared to the current tanker. When the fuel offload start/stop capability was provided on the boom telescope control the boom operators felt that, compared to the current tanker, their workload stayed the same, safety was not affected, but aerial refueling procedures became complicated. When the preselect offload capability was added to those totalizers, indicators, and gauges boom operator workload decreased, safety was either enhanced or not affected, but aerial refueling procedures were still made more complicated when compared to the current tanker.

When asked to rate how much of a requirement existed for the extra boom station controls and displays in 3-man operations, the boom operators responded that these items were extremely useful and greatly enhanced mission performance. However, when they were asked to rate the quality of the layout of the aft boom station in enhancing mission accomplishment, the result was a less than "GOOD" rating. The boom operators were more satisfied with the layout of the forward boom station, giving it a "GOOD" to "VERY GOOD" rating.

They judged the requirement for air refueling on-off pump switches at the aft boom operator's station for 3-man operations as being quite useful, a feature that would noticeably enhance mission performance. They were more enthusiastic about the capabilities provided by having weight and balance and take/off landing data calculations computerized. These capabilities were judged as extremely useful ones and would enhance mission performance greatly.

After the simulation exercises, the boom operators expressed more of an eagerness to perform in-flight duties that they do not now perform. However, when they were asked how willing they would be to perform additional duties if the increased responsibility was accompanied with an increase in training, rating, and pay, the simulation exercises made negligible difference-- the boom operators were very eager both before and after simulation to perform extra duties. When given a list of various tasks connected with the tanker mission and asked which required no training and which required some training, the boom operators demonstrated very little shift of opinion between their pre-simulation and post-simulation responses. It was generally agreed that the following tasks would require at least some amount of training: copying and decoding messages, monitoring present position and progress, communicating with cell formation and command post, rendezvous communication, monitoring weather radar and ground mapping radar, fuel management, monitoring flight instruments, aiding in directing an airborne radar approach, map reading, completing the flight log, computing take-off and landing data, map and chart management, and completing the fuel and comm log.

B. Responses to Other Design Features

There was widespread agreement among pilots and copilots as to the quality level of the various avionics and hardware of the crew station design. Of the front panel items (pilot/copilot front instrument panels and center instrument panel), only the placement of the master caution light caused concern. While all other items were rated from "GOOD" to "EXCELLENT", the master caution light was rated from very bad to fair. All other crew station avionics including items on the forward center console, the overhead panel, the aft center console, and the pilot/copilot side instrument panels received most or all of their ratings in the good to excellent range.

The ratings from both the pilots and copilots concerning the quality of the miniature toggle switches used on some of the aircraft subsystems were close to (VERY GOOD). The majority of pilots and copilots also said they required two UHF radios, one VHF radio, and one HF radio. When asked the same question about navigation equipment, the majority of pilots and copilots said they required one doppler, two inertial navigation systems, two VORs, two TACANs, one ADF, two ILSs, one attitude heading reference system, two nav management CDUs, one ground mapping radar, and no sextant.

None of the pilots' data indicated that an accelerometer was required, however, two of the copilots thought that one placed on the front instrument panel would greatly enhance mission performance. All pilots and copilots rated the capabilities provided by the selectable digital readouts on the engine instruments and subsystems pressures and quantities as being great enhancements to mission performance, and most went as far as to indicate that the readouts were absolutely necessary to perform the mission. The ability to have emergency checklists integrated with the annunciator panel and automatically displayed on a CRT met with a wide gamut of opinion from both pilots and copilots. No clear consensus emerged, with the opinions ranging from an extremely useful enhancement to mission performance to an only sometimes useful device that wouldn't really enhance mission performance.

A majority of the crews indicated that the following systems should be completely automated: takeoff computations, approach/landing computations, and a print-out of engine performance. Crews split evenly on completely automating fuel management and radar pressurization controls. A majority of the crews indicated that the following systems should be computer programmable: center of gravity calculations, takeoff and landing data, fuel management, fuel plan, nav aid tuning, APN-69 beacon, hold information, rendezvous information, flight plan information, and preflight information.

The readability of the caution/warning annunciator panel was given high ratings by all pilots across all missions as was the requirement for such a panel in a KC-135. The readability of the information on and the requirement for a thrust management system were also rated very high by the pilots as were the readability of and requirement for vertical scale engine and subsystem instruments. Much of the same lighted-segment technology utilized in the engine instruments was incorporated into the fuel panel, and its effectiveness was reflected in the pilots' ratings. Regardless of the mission, they highly rated the fuel panel layout quality, the requirement for such a device, its digital displays readability, and its overall useability and ease of fuel flow tracking.

None of the crews indicated that they ever confused the altitude alert display with the angle of attack indexer; the majority indicated that use of the altitude alert system caused their workload to decrease; and an identical majority said that the altitude alert tone was helpful.

The boom operators were unanimous in indicating that it was necessary to have both the center console area and the old nav station accessible to them and that they liked the way the jump seat maneuvered between the two crew stations. As did the majority of pilots and copilots, all the boom operators felt that the altitude alert tone was helpful.

Of the items on the front and center instrument panels that the boom operators were asked to rate for quality of location (for monitoring purposes), only the INS mode control received low marks (poor to fair). All other instruments received good to excellent ratings. In rating the instruments' locations on the forward boom station, all boom operators rated all the instruments very good to excellent.

SECTION V

DISCUSSION

The TAACE Program simulation phase was conducted to verify the findings of earlier analysis and mockup work that had concluded it was feasible to operate the KC-135 with a three person crew: pilot, copilot, and "up-graded" boom operator. The simulation work reported herein supported the conclusions of the earlier activity -- given the proper avionics capabilities and crew duties and responsibilities, operating the KC-135 with reduced crew complement remains feasible. This conclusion is based on both the performance of the crews during the simulation exercise, and their opinions regarding the useability of the crew system concepts they evaluated.

The simulation study clearly demonstrated that the single most important capability needed to effect a reduction in crew size is a modern navigation management capability useable by both the pilot and copilot at any time during flight. A second important modification is the up-grading of the boom operator's job coupled with the automation of some of the refueling functions accomplished from the boom pod. Finally, some modification/improvement to selected cockpit controls and displays is also required.

A. Navigation Management Capability

If only two pieces of hardware could be added to the tanker in the event of a reduction in crew size, all crew members would select the navigation management system, - the CDUs and closely associated horizontal situation displays. These systems provide the pilot and copilot with information defining the aircraft's orientation in space and time. Currently, the navigator is the only crew member who can provide this quick and precise description of aircraft positioning in relation to the flight plan and other aircraft in the formation.

The composite design navigation management system could display six sequential waypoints at one time as well as store many hundred additional. Also, the system had the capability to store the identifiers for all the nav aids in the world, any one of which could then be entered as a waypoint in the flight plan through less than ten keypunches. Furthermore, fuel status was automatically updated by the mission computer, as was the aircraft's present position in relation to the flight plan and all waypoints, (i.e. estimated time of arrival, time and distance to waypoint). All the while, the system maintained the flexibility to calculate take-off and landing data and CG computations. Holding and rendezvous patterns could easily be programmed in three steps and could be inserted into the flight plan in two or three steps. During simulation, with the nav system fully dynamic and responsive to computer inputs, the data crews were able to assess page formats, hardware operability and overall system performance. As was reported in the results section of this report, there was widespread and consistent agreement within and among the subject crews about the adequacy of the navigation system and its displays in helping them accomplish the aerial refueling mission.

All crew members judged the HSDs as being vastly superior to standard HSIs in helping to accomplish the refueling mission. The HSDs and nav management system worked in harmony with each other and provided to the crew the necessary information to stay on the flight plan. The majority of the time both the pilot and copilot would utilize some variation of a moving map display on the HSD (i.e. perhaps different ranges would be selected or different types of radar overlays would be used). In the absence of a navigator on the aircraft, weather information, formation position, and navigation information must be concisely and immediately available to either pilot. The subject crews utilized all available modes of operation on the HSDs and exercised and evaluated those capabilities in reference to the particular phase of flight or set of circumstances that the HSD mode was designed to handle. Also, because of the absence of the navigator, the ability to overlay the flight plan route with appropriate radar data reduced the amount of around-the-cockpit scanning that is presently needed and eliminated the requirement for either pilot to mentally calculate or interpret the relative locations of the flight plan points and the radar returns. Around-the-cockpit scanning was further reduced by displaying (digitally) frequently used flight parameters on the perimeter of the HSD. The crews' subjective data reflected the fact that the capabilities provided were all essential to mission accomplishment and that these capabilities were of the proper scope so as to provide enough information to each pilot to handle and navigate the aircraft, but not to overload them with superfluous data.

B. Boom Operator Up-Grade

The crews felt that the workload level required to fly the composite configuration was not significantly greater than the workload level required to fly the present day tanker. Although some concern was expressed about aircraft and engine systems monitoring and radar operation, in general the crews demonstrated high degrees of confidence regarding their abilities to fly and navigate the aircraft without a navigator. However, the fact that the boom operator was elevated to the status of a flight systems operator seemed to be crucial in shaping this opinion. The pilots and copilots were nearly unanimous in indicating that, even in the event of one pilot incapacitation, all three missions could have been accomplished and the aircraft returned home safely. This was not the feeling if the boom operator were not up-graded. Crew workload and an up-graded boom operator are clearly interrelated, and based on the simulation crews' comments, it is apparent that an upgraded boom operator would be used very efficiently aboard a navigatorless tanker.

The boom operator would assist in accomplishing checklists, making certain radio calls, act as navigation backup to the pilot and copilot, and provide as much systems monitoring support as he could in addition to working the boom during refueling. With the boom operator so utilized, the pilots and copilots felt that their workload would not be significantly altered from the present day tanker.

There was some disagreement among the pilots and copilots as to the particular improvements needed at the aft boom station to make the boom operator a more productive member of the crew. For example, the pilots and copilots differed noticeably in their opinions regarding the need to add transfer fuel flow rate, totalizer gauges, fuel quantity gauges, and aerial refueling pump switches to the aft boom station. The boom operators agreed more with the copilots than with the pilots when indicating that such devices were not as useful as they might at first have seemed. In the case of the boom operators, it is understandable that they indicated that such devices made aerial refueling procedures more complicated when compared to the current tanker because these systems required a great amount of monitoring duties during refueling that are not now required. Also, automatic fuel offloading start/stop capability added to the fuel flow gauges, and totalizers did not, in the boom operators' opinions, alter their workload levels significantly but instead, made overall aerial refueling procedures more complicated. The copilots generally agreed that the flow gauges and totalizers did not reduce their workload during refueling. The pilots, however, felt that their workload was reduced by adding these devices to the aft boom station.

The most significant finding seems to be that effective utilization of the boom operator is not so much a function of hardware modifications but, as mentioned earlier, increased boom operator responsibilities and crew duties integrated with those of the pilots'. However, some hardware upgrade was felt to be desirable;

e.g., fuel off-load totalizers and auto off-load capability.

C. Other Control-Display Modifications

Other changes to the cockpit included major modifications to the fuel control panel located forward of the throttles and the engine instruments located on the center instrument panel. Also, a master caution and warning system was added.

1. Fuel Control Panel

In order to accommodate the installation of a navigation management CDU forward of the throttles, where the copilot could operate it, a new, smaller fuel control panel was required. Previous analysis had stressed the importance of incorporating a schematic illustration of fuel flow into any new panel installed in the tanker. The present KC-135 fuel panel uses this approach, and it is an effective piece of equipment. The "Composite" design fuel panel met this requirement, but it also replaced the large valve switches with smaller push-button devices; the round-dial fuel quantity gauges, with digital readouts; and the pump switches, with miniaturized toggle switches. Finally, the fuel flow lines were illuminable as a function of pump and valve configuration. The design of the fuel panel was considered to be excellent. The fuel flow lines, because they were illuminated when a particular flow pattern was chosen, were said to be a significant improvement over the present fuel panel -- they allowed quick determination of fuel tracking in addition to switch position cues. The crews also found the panel layout, which was similar to the present fuel panel, to be easy to learn.

2. Engine Instruments

The round-dial engine gauges were replaced with vertical-scale lighted segment devices that would not only use less panel space, but it was thought also, improve engine performance monitoring. The data supported these hypotheses: the instruments were easy to read and interpret and allowed quick detection of system malfunctions occurring to only one engine. Furthermore, because these devices required less panel space than conventional round-dials, all engine instrumentation along with hydraulic oil quantity and pressure indications were consolidated into one geographically contiguous area reducing around-the-cockpit scanning.

3. Master Caution and Warning System

The concept of the centralized caution/warning annunciator panel received high subjective ratings from the crew. Its use virtually eliminated the necessity for the pilots to check around the cockpit for any lit malfunction indicators. Only the placement and brightness of the master caution lights caused concern among the crews. Although they were placed on the glare-shield, they were not placed directly in front of each pilot. This, coupled with the fact that the lights were not quite bright enough left them short of being the good attention grabbers they must be.

Conclusion

The TAACE simulation demonstrated that it is reasonable to consider operating the KC-135 tanker with a crew of three. The basic control and display capabilities needed to accomplish this include an integrated navigation management system, relocated controls to place all necessary equipment within reach of at least one pilot, and modified existing systems (fuel panel, engine instrumentation) to optimize workload. Finally, the boom operator position should be upgraded to a Positive Control crew member, with new duties added to these currently performed, thus making better use of the third individual on the crew.

Volume II of this report describes a modified composite design, complying with the results of the simulation study. The companion report, AFWAL-TR-81-3010, "KC-135 Crew System Criteria", (Ref. 4) presents - generalized design criteria and guidance for implementing a reduction in the KC-135 crew complement.

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